ISSN 2359-6562 (ONLINE) 2359-6562 (CD-ROM)

TAMANHO ÓTIMO DE PARCELA EM ERVILHA FORRAGEIRA

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RESUMO: O objetivo deste trabalho foi determinar o tamanho ótimo de parcela (Xo) para avaliar a produtividade de matéria fresca de ervilha forrageira (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. ‘Iapar 83’, e verificar se Xo difere entre três métodos de estimação. Para isso, foram conduzidos seis ensaios de uniformidade, sendo três na primeira data de semeadura (03 de maio de 2021) e três na segunda data de semeadura (26 de maio de 2021). Foi avaliada a produtividade de matéria fresca em 216 unidades experimentais básicas (UEB) de 1 m × 1 m (36 UEB por ensaio). A UEB foi formada por duas fileiras de 1,0 m de comprimento, espaçadas 0,50 m entre fileiras, totalizando 1,0 m^2. O Xo foi determinado pelos métodos da curvatura máxima modificado (CMM), do modelo linear de resposta com platô (LRP) e do modelo quadrático de resposta com platô (QRP). O Xo difere entre os métodos e decresce na seguinte ordem: QRP (11,27 m^2), LRP (7,14 m^2) e CMM (5,03 m^2). O Xo para avaliar a produtividade de matéria fresca de ervilha forrageira, cv. ‘Iapar 83’, é 7,14 m^2 e o coeficiente de variação estabiliza a partir desse tamanho.

Palavras-chave: *Pisum sativum* subsp. *arvense* (L.) Poir, dimensionamento experimental, curvatura máxima modificado, modelo linear de resposta com platô, modelo quadrático de resposta com platô.

OPTIMAL PLOT SIZE IN THE FORAGE PEA

ABSTRACT: The objective of this work was to determine the optimal plot size (Xo) for evaluating the fresh matter productivity of forage pea (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'Iapar 83' and to determine whether Xo differs among three estimation methods. Six uniformity trials were carried out. Three trials were conducted on the first sowing date (May 3, 2021), and three trials were conducted on the second sowing date (May 26, 2021). Fresh matter productivity was evaluated in 216 basic experimental units (BEUs) of 1 m × 1 m (36 BEUs per trial). The BEU was formed by two rows of 1.0 m in length spaced 0.50 m between rows, totaling 1.0 ^{m2}. Xo was determined via the modified maximum curvature method (MMC), the model linear response with plateau (LRP) and the model quadratic response with plateau (QRP). Xo differs among the methods and decreases in the following order: QRP (11.27 ^{m2}), LRP (7.14 ^{m2}) and MMC (5.03 ^{m2}). The Xo used to evaluate the fresh matter productivity of the forage pea cultivar 'Iapar 83' is 7.14 m2, and the coefficient of variation stabilizes from that size.

Keywords: *Pisum sativum* subsp. *arvense* (L.) Poir, experimental design, modified maximum curvature, model linear response with plateau, model quadratic response with plateau.

1. INTRODUCTION

The experimental error consists of the variation between treatment repetitions and occurs randomly in the experiment. Importantly, the experimental error is as small as possible so that smaller differences between treatment means are identified as significant, that is, not attributed to chance. The coefficient of variation (PIMENTEL-GOMES,

Recebido em 22/12/2021 e aprovado para publicação em 08/02/2023
DOI: http://dx.doi.org/10.17224/EnergAgric.2023v38n1p47-57

2009) is one of the experimental statistics used to evaluate experimental precision. This statistic has an inverse relationship with experimental precision; that is, the higher the score is, the lower the experimental precision, and consequently, greater differences between mean estimates are necessary for them to be considered significant.

Research shows that with increasing plot size, there is a nonlinear decrease in the coefficient of variation (CARGNELUTTI FILHO *et al.*, 2021a, 2021b), that is, an improvement in experimental precision. Given this response pattern, it is possible to use data from uniformity tests (blank experiments) and plan different plot sizes (X) by grouping adjacent basic experimental units (UEBs) and estimating the coefficient of variation ($CV_{(X)}$). between the UEB.

Using the modified maximum curvature method (CMM) (MEIER; LESSMAN, 1971), the linear response model with a plateau (LRP) (PARANAÍBA; FERREIRA; MORAIS, 2009) and the quadratic response model with a plateau (QRP) (PEIXOTO; FARIA; MORAIS, 2011), it is possible to relate $CV_{(X)}$ as a function of X and determine the optimal plot size (Xo) and the coefficient of variation in the optimal plot size (CV_{Xo}).

Different results among the CMM, LRP and QRP methods have been obtained for passion fruit crops (PEIXOTO; FARIA; MORAIS, 2011), radish (SILVA *et al.*, 2012), coffee trees (MOREIRA *et al.*, 2016), sweet potato (GONZÁLEZ *et al.*, 2018), cabbage (GUARÇONI *et al.*, 2017), cactus forage (GUIMARÃES *et al.*, 2019), millet + sunn hemp ochroleuca + sunn hemp spectabilis (CARGNELUTTI FILHO *et al.*, 2021a), and buckwheat (CARGNELUTTI FILHO *et al.*, 2021 b), highlighting the importance of using more than one method in determining the optimal plot size.

Plot size has been investigated to evaluate the fresh matter of forage pea (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'BRS Sulina' (CARGNELUTTI FILHO *et al.*, 2015) via the maximum curvature method of the coefficient of variation model (PARANAÍBA; FERREIRA; MORAIS, 2009).

However, in this study, the CMM, LRP and QRP methods were not used. It is assumed that the use of these methods, in new uniformity tests and with another forage pea cultivar (cv. 'Iapar 83'), can generate different plot sizes and, therefore, add important information for planning the experiments, aiming for greater experimental precision for the only two cultivars of forage pea registered with the Ministry of Agriculture, Livestock and Supply.

Thus, the objective of this work was to determine the optimal plot size (Xo) to evaluate the fresh matter productivity of forage pea (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'Iapar 83' and to determine whether Xo differs among the three estimation methods.

2 MATERIALS AND METHODS

Six uniformity tests with the forage pea crop (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'Iapar 83' were conducted in an experimental area located at 29°42'S, 53°49'W and 95 m altitude. In this location, the climate is humid subtropical Cfa (ALVARES *et al.*, 2013), and the soil is Dystrophic Red Argisol (SANTOS *et al.*, 2018).

The cultivar 'Iapar 83' was sown on two dates (May 3, 2021, and May 26, 2021). Three uniformity tests were carried out on each sowing date. In the six trials, sowing was carried out in rows, spaced 0.50 m between rows, and 24 seeds were placed per meter of row. The base fertilizer was 35 kg ha $^{-1}$ of N, 135 kg ha $^{-1}$ of P_2O_5 and 135 kg ha $^{-1}$ of K_2O.

In each uniformity test, an area measuring 6 m × 6 m (36 m^2) was demarcated and divided into 36 basic experimental units (UEBs) measuring 1 m × 1 m (1 m^2), forming a matrix of six lines and six columns. . The UEB was formed by two rows that were 1.0 m long and spaced 0.50 m between rows, totaling 1.0 m^2.

Fresh matter productivity (MF) assessments were carried out on August 30, 2021, and September 17, 2021, in tests installed on May 3, 2021, and May 26, 2021, that is, 119 and 114 days after sowing, respectively. On these dates, the forage pea was at the R5 stage; that is, the crop had a fully formed legume and was beginning to fill with grains. For these evaluations, in each 1 m^{2} UEB, the plants were cut close to the soil surface, and the fresh matter was weighed on a digital scale (accuracy: 1 g), obtaining the fresh matter productivity (MF, gm $^{-2}$) in 216 UEBs (6 tests × 36 UEBs per test).

For each uniformity test, based on the MF data from the 36EB, plots with X_L UEB adjacent in the row and X_C UEB adjacent in the column were planned. Plots with different sizes and/or shapes were planned as follows: ($X=X_L \times X_C$), that is, (1×1), (1×2), (1×3), (1×6), (2×1), (2×2), (2×3), (2×6), (3×1), (3×2), (3×3), (3×6), (6 ×1), (6×2) and (6×3). The acronyms X_L, X_C and for each plot size (X) were as follows: n - number of plots with X size UEB (n=36/X); $M_{(X)}$ - average of plots with X UEB in size; and $CV_{(X)}$ - coefficient of variation (in %) between the plots of X UEB of size.

For each trial, estimates of the coefficient of determination (R 2), the optimal plot size (Xo) and the coefficient of variation in the optimal plot size (CV Xo, %) were obtained via the modified maximum curvature method (CMM) (MEIER; LESSMAN, 1971), the linear response model with plateaus (LRP) (PARANAÍBA; FERREIRA; MORAIS, 2009) and the quadratic response model with plateaus (QRP) (PEIXOTO; FARIA; MORAIS, 2011). In these three methods, models of the dependent variable ($CV_{(X)}$, in %) are adjusted as a function of the independent variable (X, in UEB). When adjusting the models, the average $CV_{(X)}$ between plots of the same size but of different shapes was used.

Comparisons of *the* mean estimates *of* R^2, Xo and CV Student's t test (two-sided) for dependent samples at 5% significance. Statistical analyses were carried out via Microsoft Office Excel® application and R software (R CORE TEAM, 2021).

3 RESULTS AND DISCUSSION

The average fresh matter productivity (MF) of forage pea (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'Iapar 83', on the first sowing date (1694 gm $^{-2}$)) did not differ from the average value obtained on the second sowing date (1740 gm $^{-2}$) (t = 0.515204; p value = 0.633575, 4 degrees of freedom). The average MF among the six uniformity tests was 1717 gm $^{-2}$, which is equivalent to 17.17 Mg ha $^{-1}$ (Tables 1 and 2). Similar results were obtained by Cargnelutti Filho *et al.* (2015) for the MF of forage pea (*Pisum sativum* subsp. *arvense* (L.) Poir) cv. 'BRS Sulina' evaluated at 92 (1733.97 gm $^{-2}$), 98 (2144.46 gm $^{-2}$) and 106 (2172.59 gm $^{-2}$) days after sowing, highlighting the potential of this crop as a ground cover crop.

The average coefficient of variation (CV) of the three tests installed on the first sowing date (30.33%) did not differ from the average of the three tests installed on the second sowing date (24.01%) (t = 1.521092; p value = 0.202882, 4 degrees of freedom), with an overall average of 27.17% (Tables 1 and 2). This suggests similar plot sizes between sowing dates.

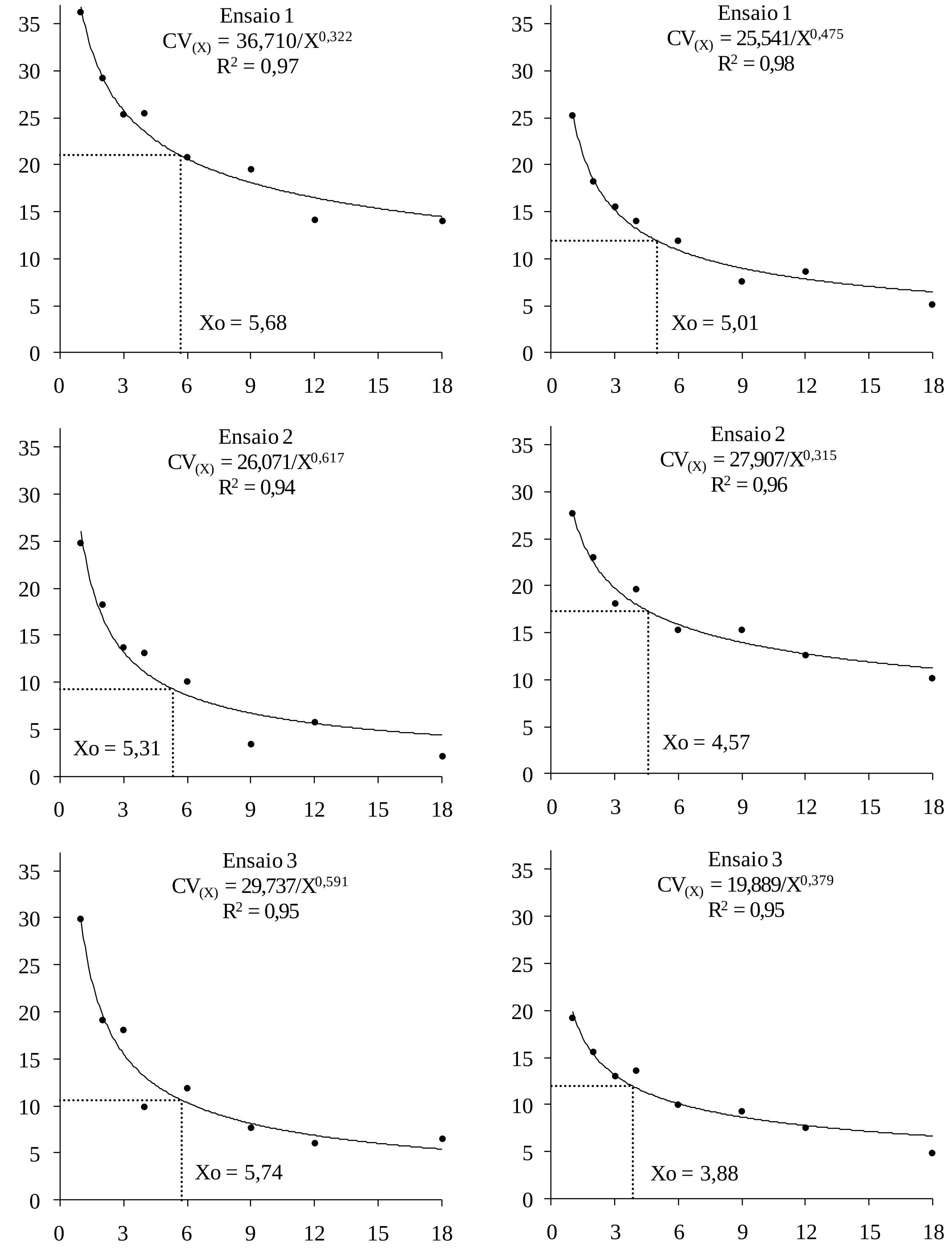
There was a nonlinear decrease in the coefficient of variation [$CV_{(X)}$] with increasing planned plot size (X) (Table 1, Figures 1, 2 and 3). A tendency toward stabilization of the $CV_{(X)}$ can also be seen, which highlights the importance of using the CMM, LRP and QRP methods to determine the optimal plot size to improve experimental precision.

Table 1. Average [M $_{(X)}$, in g] and coefficient of variation (CV $_{(X)}$, in %) of fresh matter productivity of forage pea in uniformity trials conducted on two sowing dates.

Seeding	X_L	X_C	X	n	$M_{(X)}$	$CV_{(X)}$	$CV_{(X)}^{(1)}$	$M_{(X)}$	$CV_{(X)}$	$CV_{(X)}^{(1)}$	$M_{(X)}$	$CV_{(X)}$	$CV_{(X)}^{(1)}$
						Ensaio 1			Ensaio 2			Ensaio 3	
03/05/2021	1	1	1	36	1574	36,27	36,27	1742	24,86	24,86	1767	29,85	29,85
03/05/2021	1	2	2	18	3147	29,23	29,22	3484	15,18	18,28	3535	16,76	19,07
03/05/2021	2	1	2	18	3147	29,21	-	3484	21,39	-	3535	21,38	-
03/05/2021	1	3	3	12	4721	27,42	25,32	5227	13,69	13,66	5302	17,26	18,02
03/05/2021	3	1	3	12	4721	23,22	-	5227	13,62	-	5302	18,78	-
03/05/2021	2	2	4	9	6294	25,50	25,50	6969	13,15	13,15	7070	9,88	9,88
03/05/2021	1	6	6	6	9442	23,19	20,78	10453	9,36	10,05	10604	9,32	11,90
03/05/2021	2	3	6	6	9442	25,33	-	10453	11,76	-	10604	9,29	-
03/05/2021	3	2	6	6	9442	19,01	-	10453	5,92	-	10604	11,00	-
03/05/2021	6	1	6	6	9442	15,59	-	10453	13,17	-	10604	17,98	-
03/05/2021	3	3	9	4	14162	19,56	19,56	15680	3,43	3,43	15907	7,70	7,70
03/05/2021	2	6	12	3	18883	22,75	14,14	20906	6,03	5,77	21209	2,93	6,06
03/05/2021	6	2	12	3	18883	5,53	-	20906	5,52	-	21209	9,20	-
03/05/2021	3	6	18	2	28325	23,50	14,06	31359	4,10	2,10	31813	4,90	6,47
03/05/2021	6	3	18	2	28325	4,63	-	31359	0,09	-	31813	8,04	-
						Ensaio 1			Ensaio 2			Ensaio 3	
26/05/2021	1	1	1	36	1870	25,19	25,19	1673	27,66	27,66	1678	19,17	19,17
26/05/2021	1	2	2	18	3740	19,86	18,22	3346	21,05	23,06	3355	15,78	15,61
26/05/2021	2	1	2	18	3740	16,58	-	3346	25,07	-	3355	15,44	-
26/05/2021	1	3	3	12	5610	18,95	15,58	5019	15,44	18,14	5033	13,79	12,98
26/05/2021	3	1	3	12	5610	12,20	-	5019	20,84	-	5033	12,18	-
26/05/2021	2	2	4	9	7480	14,01	14,01	6692	19,61	19,61	6710	13,62	13,62
26/05/2021	1	6	6	6	11220	17,17	11,87	10038	7,33	15,31	10066	8,73	9,96
26/05/2021	2	3	6	6	11220	11,59	-	10038	15,23	-	10066	12,16	-
26/05/2021	3	2	6	6	11220	9,57	-	10038	19,85	-	10066	10,07	-
26/05/2021	6	1	6	6	11220	9,15	-	10038	18,83	-	10066	8,88	-
26/05/2021	3	3	9	4	16831	7,64	7,64	15057	15,27	15,27	15099	9,22	9,22
26/05/2021	2	6	12	3	22441	12,85	8,61	20076	5,95	12,60	20131	8,01	7,56
26/05/2021	6	2	12	3	22441	4,38	-	20076	19,24	-	20131	7,11	-
26/05/2021	3	6	18	2	33661	9,05	5,10	30114	3,79	10,16	30197	0,81	4,79
26/05/2021	6	3	18	2	33661	1,15	-	30114	16,52	-	30197	8,77	-

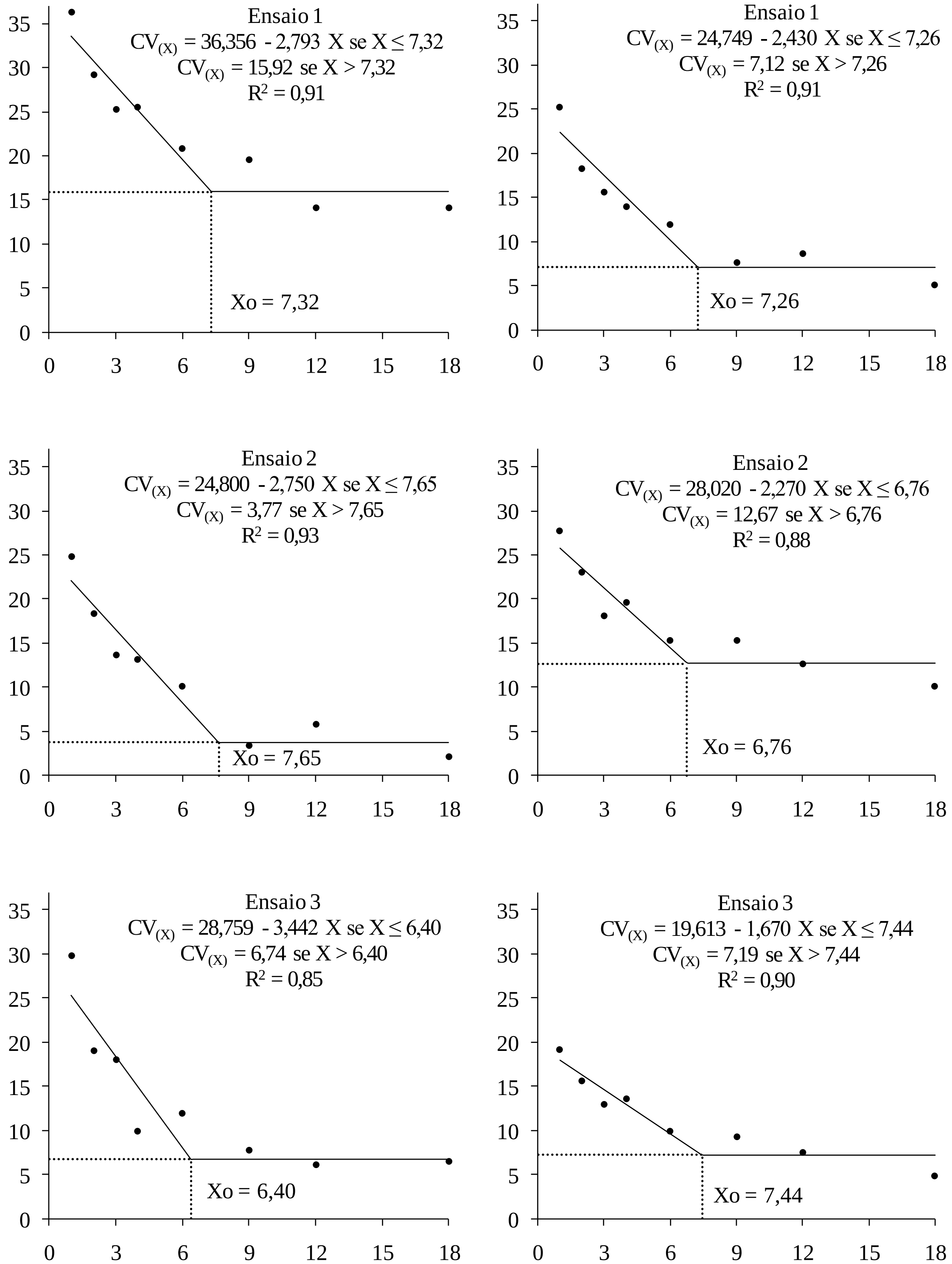
X_L - Number of adjacent basic experimental units (UEBs) in the line; X_C - number of adjacent UOBs in the column; n - number of parcels with X UEB in size; X - planned plot size ($X=X_L \times X_C$); CV $_{(X)}^{(1)}$ - average CV between plots of the same size but of different shapes used to adjust the models.

Figure 1. Relationship between the coefficient of variation, in % (ordinate axis), and the plot size, in m ^{2} (abscissa axis), in the modified maximum curvature method.



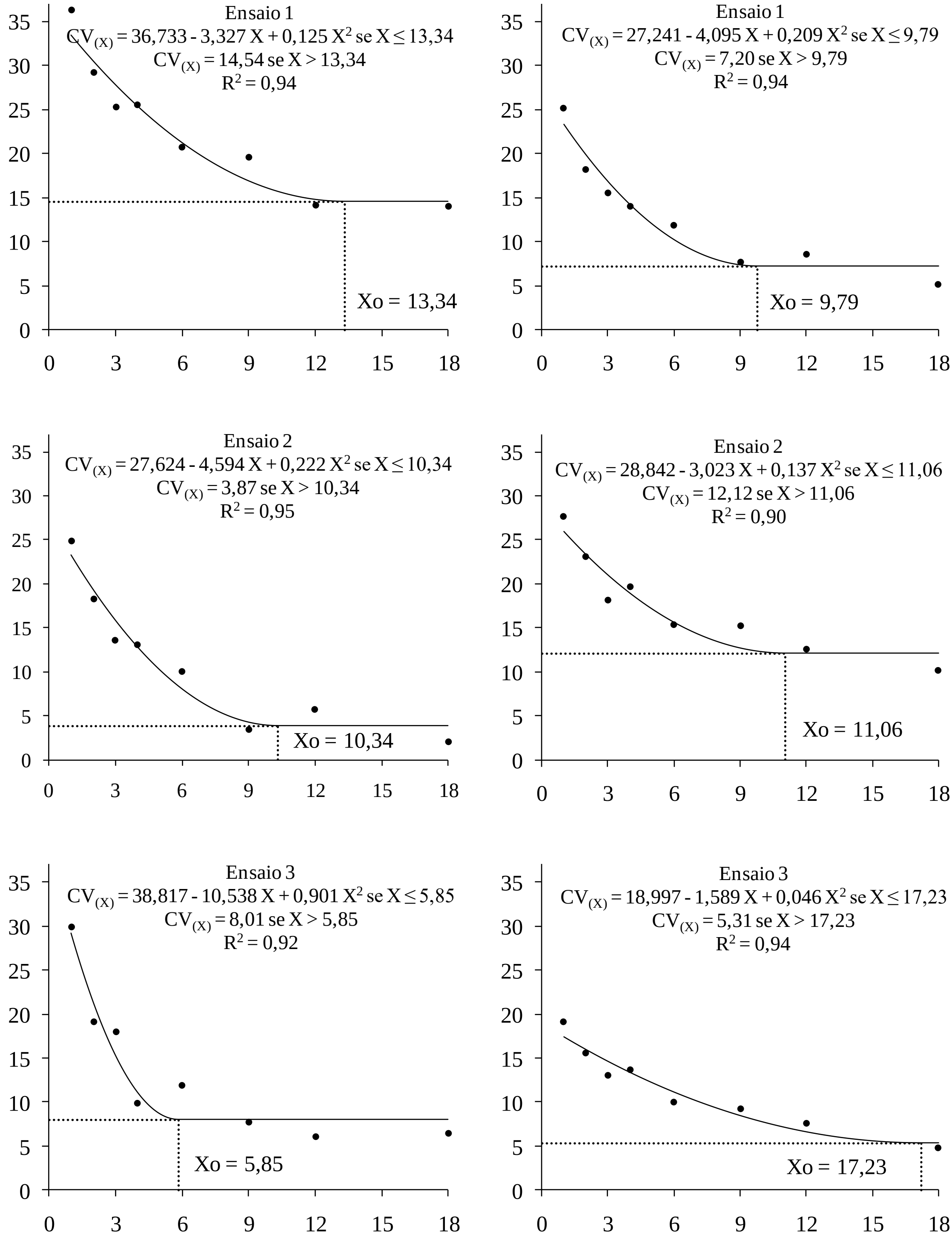
Left column - sowing trials on 05/03/2021; right column - sowing trials on 05/26/2021.

Figure 2. Relationship between the coefficient of variation, in % (ordinate axis), and the plot size, in m^2 (abscissa axis), in the linear response model with a plateau.



Left column - sowing trials on 05/03/2021; right column - sowing trials on 05/26/2021.

Figure 3. Relationship between the coefficient of variation, in % (ordinate axis), and the plot size, in m^2 (abscissa axis), in the quadratic response model with a plateau.



Left column - sowing trials on 05/03/2021; right column - sowing trials on 05/26/2021.

The average coefficients of determination (R^2) among the six uniformity tests were 0.96, 0.90 and 0.93 for the CMM, LRP and QRP methods, respectively (Table 2, Figures 1, 2 and 3). The three methods presented R2 values close to unity ($R^2 \geq 0.90$), indicating the credibility of the estimates of Xo and CV_{Xo} calculated from these models.

Table 2. The fresh matter productivity (MF), coefficient of variation (CV), and parameter estimate a are the coefficient of determination (R^2), the optimal plot size (Xo) and the coefficient of variation in the optimal plot size (CV_{Xo}).

Seeding	Rehearsal	MF (gm^{-2})	CV (%)	*The*	*B*	*w*	R^2	Xo (m^2)	CV_{Xo} (%)
Maximum modified curvature: $CV_{(X)} = a/X^b + \varepsilon$									
05/03/2021	1	1574	36.27	36,710	0.322	-	0.97	5.68	20.98
05/03/2021	two	1742	24.86	26,071	0.617	-	0.94	5.31	9.30
05/03/2021	3	1767	29.85	29,737	0.591	-	0.95	5.74	10.59
05/26/2021	1	1870	25.19	25,541	0.475	-	0.98	5.01	11.89
05/26/2021	two	1673	27.66	27,907	0.315	-	0.96	4.57	17.28
05/26/2021	3	1678	19.17	19,889	0.379	-	0.95	3.88	11.91
Average		1717	27.17				0.96A	5.03C	13.66A
Linear response model with plateau: $CV_{(X)} = \begin{cases} a + bX + \varepsilon & se\ X \leq Xo \\ p + \varepsilon & se\ X > Xo \end{cases}$									
05/03/2021	1	1574	36.27	36,356	-2,793	-	0.91	7.32	15.92
05/03/2021	two	1742	24.86	24,800	-2,750	-	0.93	7.65	3.77
05/03/2021	3	1767	29.85	28,759	-3.442	-	0.85	6.40	6.74
05/26/2021	1	1870	25.19	24,749	-2,430	-	0.91	7.26	7.12
05/26/2021	two	1673	27.66	28,020	-2.270	-	0.88	6.76	12.67
05/26/2021	3	1678	19.17	19,613	-1.670	-	0.90	7.44	7.19
Average		1717	27.17				0.90 B	7.14 B	8.90B
Quadratic response model with plateau: $CV_{(X)} = \begin{cases} a + bX + cX^2 + \varepsilon & se\ X \leq Xo \\ p + \varepsilon & se\ X > Xo \end{cases}$									
05/03/2021	1	1574	36.27	36,733	-3.327	0.125	0.94	13.34	14.54
05/03/2021	two	1742	24.86	27,624	-4,594	0.222	0.95	10.34	3.87
05/03/2021	3	1767	29.85	38,817	-10.538	0.901	0.92	5.85	8.01
05/26/2021	1	1870	25.19	27,241	-4.095	0.209	0.94	9.79	7.20
05/26/2021	two	1673	27.66	28,842	-3.023	0.137	0.90	11.06	12.12
05/26/2021	3	1678	19.17	18,997	-1.589	0.046	0.94	17.23	5.31
Average		1717	27.17				0.93A	11.27A	8.51B

Means of R^2, Xo and CV

The average optimal plot size (Xo) among the six uniformity tests differed among the three methods, with values of 11.27 m2 via the QRP, 7.14 m2 via the LRP and 5.03 m2 via the CMM (Table 2, Figures 1, 2 and 3). Therefore, it can be inferred that plot size depends on the estimation method.

of variation in the optimal plot size (CV 8.51%), which did not differ from each other (Table 2, Figures 1, 2 and 3). These results, according to the classification of Pimentel-Gomes (2009), indicate high experimental precision using the plot sizes determined by the LRP and QRP methods (CV ≤ 10%) and medium precision with the CMM (10% < CV ≤ 20%).

Although the plot sizes are different between the LRP (7.14 m^2) and QRP (11.27 m^2) methods, they result in similar experimental precisions, as the CV_{Xo} values do not differ. This proves that from a certain plot size onward, the gains in precision (decrease in the coefficient of variation) with increasing plot area are insignificant (Figures 1, 2 and 3). Therefore, the use of plots measuring 7.14 m2 can be recommended for planning future experiments.

This size of 7.14 m2 is relatively greater than the 5.03 m2 needed to evaluate the MF of forage pea, cv. 'BRS Sulina' (CARGNELUTTI FILHO *et al.*, 2015). Notably, the authors used another method, that is, the maximum curvature of the coefficient of variation model (PARANAÍBA; FERREIRA; MORAIS, 2009).

Research has shown results similar to those of the present study, that is, decreasing estimates of Xo in the following order: QRP, LRP and CMM (SILVA *et al.*, 2012; MOREIRA *et al.*, 2016; GUARÇONI *et al.*, 2017; GONZÁLEZ *et al.*, 2018; GUIMARÃES *et al.*, 2019; CARGNELUTTI FILHO *et al.*, 2021a, 2021b). This highlights the importance of using different methods and the possible underestimation of the plot size determined by the CMM, overestimation by the QRP method and suitability by the LRP method. However, it is important to carry out more studies with other variables, crops and methods before defining the ideal method for determining the optimal plot size.

4 CONCLUSIONS

The optimal plot size differs among methods and decreases in the following order: quadratic response model with a plateau (11.27 ^{m2}), linear response model with a plateau (7.14 ^{m2}) and modified maximum curvature (5.03 m2$^{)}$. The optimal plot size for evaluating the fresh matter productivity of forage pea, cv. 'Iapar 83', is 7.14 m2, and the coefficient of variation stabilizes at this size.

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